Evaluation of UltraSTAR: Performance of a Collaborative Structured Data Entry System

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The UltraSTAR structured data entry system is now in routine use for reporting ultrasound studies at Brigham and Women's Hospital, having been used for 3722 reports in its first ten months of service. Reports entered through GUI-based forms are uploaded via HL7 to a radiology information system and distributed through a hospital network. UltraSTAR introduces collaborative reporting, in which nonmedical and medical staff collaborate to produce a single report for each patient visit.

Performance of UltraSTAR was measured as user satisfaction, data entry time, report completeness, free text annotation rate, and referring-physician satisfaction with reports. Results show high satisfaction with UltraSTAR among radiologists and acceptance of the system among ultrasound technicians. Data entry times averaged 5.3 minutes per report. UltraSTAR reports were slightly more complete than comparable narrative reports. Free text annotations were needed in only 25.2% of all UltraSTAR reports. Referring physicians were neutral to slightly positive toward UltraSTAR's outline-format reports.

UltraSTAR is successful at structured data entry despite somewhat long reporting times. Its success can be attributed to efficiencies from collaborative reporting and from integration with existing information systems. UltraSTAR shows that the advantages of structured data entry can outweigh its difficulties even before problems of data entry time and concept representation are solved.

INTRODUCTION

Clinical observations in a computer-based patient record may be acquired as natural language or through structured data entry. Natural language offers flexibility of expression, but summarizing natural language data requires a human encoder or automated natural-language processing (NLP). Although progress is being made in NLP [1], concepts abstracted by NLP still carry a degree of uncertainty. Structured data entry, defined here as recording observations by selecting concepts directly from a standard concept set, offers several potential advantages. Standardized observational data acquired directly from the clinician would lower the cost and increase the certainty of data summaries. Data gathered through structured data entry may also be more complete than comparable natural language records, as demonstrated in the domain of endoscopy [2]. Finally, the structured data entry process may be more directly integrated with decision support, as demonstrated by Ivory and T-Helper [3].

Attempts to implement structured data entry have had a long history. The earliest efforts used paper forms [4], or touch-sensitive screens [5, 6], but never achieved routine use. A structured data entry system implemented on a general medical ward was rejected after considerable investment [7]. Efforts in narrower subdomains have achieved more lasting use [2, 8-13], but data abstraction has remained difficult and systems have in general not been successful outside the institutions where they were developed. These efforts illustrate that challenges to structured data entry remain to be addressed. Interface techniques are needed to minimize data entry time, concept structures need to flexibly match the clinician's documentation requirements, and data entered must be integrated with existing information systems. UltraSTAR (Ultrasound STructured Attribute Reporting) was developed to address these challenges while meeting immediate needs for efficiency in report generation. In so doing, UltraSTAR introduced "collaborative reporting," in which observations and interpretations are obtained from multiple sources to comprise a single report. In the ultrasound domain, the collaboration is among technologist and radiologist. In other clinical domains, the collaboration could include nurses, physicians at different levels of training, patients, and even expert systems.

METHODS

Software

Design and Implementation. The UltraSTAR system provides structured data entry for ultrasound

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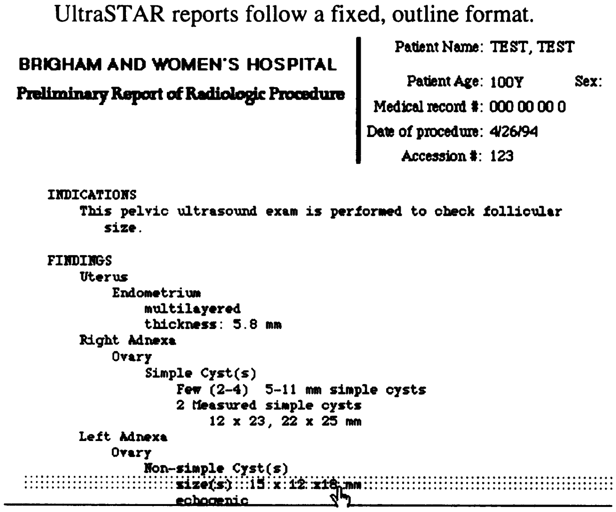
results, with preliminary reports generated by ultrasound technologists (sonographers) being later edited and signed by attending radiologists in lieu of dictation. The original design of the system has been published [14], but its main features are briefly reviewed here. Concepts are selected using checkboxes and radio buttons arranged in small forms that are displayed in overlapping windows. Any report may be saved as a template and later reused to start a new report that is then edited for the new patient. Reports are printed in an outline format that mirrors UltraSTAR's concept hierarchy (Figure 1).

UltraSTAR is implemented in SuperCard™ for the Apple Macintosh (Apple Computer, Inc., Cupertino, CA), with external functions written in Think C. (Symantec Corp, Cupertino, CA). Network communications with IDXrad (a radiology information system of IDX Corp, Burlington, Vermont) handle user identification and security, patient demographic queries, and uploading of signed reports using HL7 [15] messages. Pending reports are stored as individual Macintosh files and may be located on any Macintosh volume on the same AppleTalk network, with UltraSTAR maintaining the indices and file locks appropriate for a distributed database. When a report is signed and sent to IDXrad, its coded content is also stored on the Macintosh in a flat file for later statistical analysis.

The system is installed on four Macintosh workstations connected to IDXrad by Ethernet, using the DECnet protocol.

Figure 1
UltraSTAR reports follow a fixed, outline format.


BRIGHAM AND WOMEN'S HOSPITAL
Preliminary Report of Radiologic Procedure

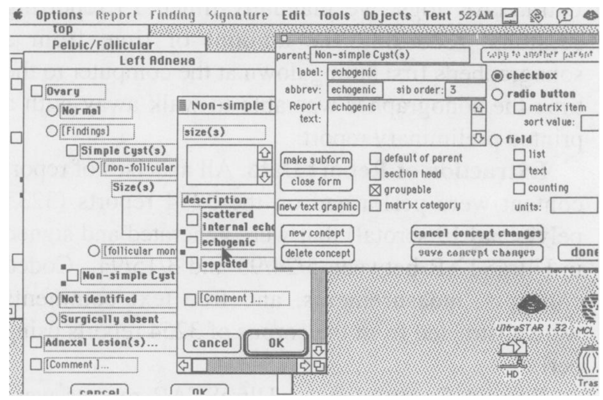
Patient Name: TEST, TEST
Patient Age: 100Y Sex:
Medical record #: 000 00 00 0
Date of procedure: 4/26/94
Accession #: 123

```
INDICATIONS
   This pelvic ultrasound exam is performed to check follicular
     size.

FINDINGS
   Uterus
      Endometrium
         multilayered
         thickness: 5.8 mm
   Right Adnexa
      Ovary
         Simple Cyst(s)
            Few (2-4) 5-11 mm simple cysts
            2 Measured simple cysts
               12 x 23, 22 x 25 mm
   Left Adnexa
      Ovary
         Non-simple Cyst(s)
            size(s): 15 x 12 x18 mm
            echogenic
```

Concept Authoring. UltraSTAR's knowledge base consists of a hierarchy of increasingly detailed concepts, each with attributes that govern its display and reporting. Each button or field in a data-entry form corresponds to a unique concept in the knowledge base. Each valid concept-modifier combination is represented in the knowledge base by a new unique concept. An authoring interface has been added to UltraSTAR that allows a domain expert to add, edit, and retire concepts from use (Figure 2).

Figure 2
UltraSTAR's concept authoring module provides a single interface for adding and retiring concepts, changing their layout on data-entry forms, and editing their attributes.



Evaluation

Sonographer and Radiologist Survey. A three-part paper questionnaire was administered to the sonographers and attending radiologists who had used UltraSTAR.

Part one of the questionnaire consisted of items that we designed for this study. These included 7 items that used a Likert-scale response (a five-point scale with 1 representing "strongly agree," 3 representing "neutral," and 5 representing "strongly disagree") to evaluate users' overall satisfaction with UltraSTAR. Because these items were previously untested, they were evaluated using methods outlined in [16]. Items that had the best covariance were formed into a mean satisfaction scale. (Scores on this scale are obtained by taking the mean of an individual's Likert-scale responses, after reversing the responses to negatively-worded items.) This scale was then evaluated with Cronbach's alpha and confirmatory factor analysis.

Part two of the questionnaire consisted of 23 items testing satisfaction with specific user interface features of UltraSTAR. These items were taken from the 26-item Questionnaire on User Interface Satisfaction (QUIS 5.0), an instrument developed and validated at the University of Maryland [17]. We deleted two items from the QUIS that were not applicable to our system and one that had poor reliability in original testing of the QUIS.

Part three of the questionnaire was a control for part two. The same 23 QUIS items were applied to evaluate the user interface of OBUS, an obstetrical calculation and reporting program that is also used by both sonographers and radiologists in the Ultrasound Department.

Data Entry Time. For every reporting sesion, UltraSTAR logs the amount of time taken from report opening to report closing. Data was extracted from the UltraSTAR session log using the perl scripting language [18]. To validate the data entry times that UltraSTAR logs, we manually timed 15 reporting sessions, recording the amount of time from a sonographer's first sitting down at the computer to the time the sonographer was able to walk away with a printed preliminary report.

Extraction of Report Data. All analyses of report content were performed on the 3254 reports (3235 pelvic and 19 scrotal) that were generated and signed in UltraSTAR between 5/24/93 and 3/15/94. Coded concepts, measurements, and free text comments were abstracted from the corpus of 3254 reports using perl.

Report Completeness. UltraSTAR reports were compared with narrative reports for content of data elements considered essential to pelvic ultrasound reporting. Seventy-one "follicular monitoring" pelvic ultrasound reports were sampled from reports dictated and transcribed into IDXrad between 5/1/93 and 7/8/93. (Reports were occasionally dictated after 5/24/93 during times of patient overload or when UltraSTAR was undergoing repair.) Content was abstracted from narrative reports by manual review. Content was abstracted from the 2222 "follicular monitoring" exams among the full corpus of 3235 UltraSTAR pelvic ultrasound reports using perl, as described above.

Referring-Physician Satisfaction with Outline Reports. A paper questionnarie consisting of 16 items was constructed to evaluate attitudes toward outline-format UltraSTAR reports as compared with dictated narrative reports. Questionnaires were given serial numbers that enabled identification of nonresponders. Forms were distributed along with a cover letter that promised anonymity, to the 12 gynecologists who were the primary recipients of UltraSTAR reports. A second copy of the form was distributed to nonresponders after two weeks. Survey evaluation was performed as described above.

Statistical Analyses. Ninty-five percent confidence intervals (95% CI) were based on the *t* distribution for variables that appeared normally distributed on normal-quantile plots. Calculations of mean, standard deviation (SD), Pearson's correlation coefficient (r), Pearson's χ^2-test, analysis of variance (ANOVA), Cronbach's alpha, and factor analysis, were performed using Stata (Stata Corp, College Station, Texas).

RESULTS

System Use

During the first 10 months of routine use (6/1/93 to 4/1/94) 3722 ultrasound reports have been generated using UltraSTAR. As UltraSTAR use has expanded to scrotal ultrasound and pelvic ultrasound on nonfertility patients, monthly volume has increased, with 730 reports generated during 3/94. At an estimated in-house transcription cost of $1.16 per report, UltraSTAR is now potentially saving the Radiology Department $847 per month.

Sonographer and Radiologist Survey

User satisfaction scale: Testing. Our questionnaire was returned by 9 of 15 sonographers and 4 of 6 attending radiologists who are currently active users of UltraSTAR. Five Likert-scale questions, shown in Table 1, form a reliable scale (Cronbach's alpha = 0.79, based on our sample of 13 responses). Factor analysis shows that one primary factor accounts for most of the variation in the responses to these five questions. We consider this factor to be the users' overall satisfaction with the UltraSTAR system and its effect on their work.

Table 1
Items forming the user satisfaction scale.

I enjoy using UltraSTAR.
UltraSTAR makes my work more difficult.
I would like to see more exam types reported with UltraSTAR.
With UltraSTAR, I feel good that my work doesn't have to be repeated.
I preferred the previous system of handwritten preliminary reports.

User satisfaction scale: Results. Sonographers were relatively neutral toward UltraSTAR, giving a mean satisfaction score of 2.9 (95% CI: 2.5–3.3), where 3 is neutral, 1 is strongly positive, and 5 is strongly negative. Attending radiologists were positive toward the system, giving a mean satisfaction score of 1.8 (95% CI 0.6–3.0).

QUIS 5.0: Results. Table 2 shows the mean responses of all users for each subscale of the Questionnaire on User Interface Satisfaction (QUIS) [17]. It also shows mean responses on the individual QUIS items for which UltraSTAR scored the best and the worst. For comparison, mean responses are shown for our users' evaluation of OBUS, along with the responses originally published in the valiation of the QUIS against DOS and WordPerfect.

Table 2

User interface satisfaction, as measured by QUIS 5.0. Each item is scored on a scale from 0 (most negative) to 9 (most positive). (Ultra=UltraSTAR, WP=WordPerfect)

QUIS subscale	Ultra	OBUS	DOS	WP
Learning	6.5	7.1	4.9	6.9
Terms and System Information	6.5	7.5	4.1	4.6
System Output	5.1	7.6	6.2	7.2
System Characteristics	4.5	6.7	5.2	7.0
QUIS item				
Learning to operate the system	7.4	7.7	3.6	5.1
Consistent use of terms throughout the system	6.8	7.4	6.4	7.5
System Speed	4.2	5.5	5.3	6.8
Error Messages	3.3	5.2	3.5	5.8

Data Entry Time

The mean of all data entry times logged by UltraSTAR for initial report generation by sonographers was 3.75 minutes (SD 2.28 min). The mean number of concepts in a report was 19 (SD 4.0). Data entry times correlated weakly with the number of concepts in a report (r = 0.37).

Fifteen manually-recorded overall session times correlated linearly with the data entry times logged for the same sessions by UltraSTAR (r = 0.92), but overall session times were 1.55 minutes longer (95% CI 0.84–2.27 min). Thus, the mean overall reporting time has been approximately 5.3 minutes per report.

Significant variation existed among individual sonographers (P<.001, ANOVA), but Figure 3 shows that considerable variance remains within each individual's data entry times.

Report Completeness

Table 3 shows completion rates for information that should be in every pelvic ultrasound report. All 2222 follicular monitoring ultrasound exams in our corpus of signed UltraSTAR reports are compared with a sample of 71 narrative reports of the same exam type.

Proportion of Free Text

Of the 3254 pelvic and scrotal ultrasound reports studied, 820 (25.2%) contained at least one free text annotation. The 200 text comments modifying the uterus were examined and categorized. Forty three comments (22%) described an echogenic or hypoechoic focus or area within the uterus, using fairly stereotypical descriptors. Thirty four comments (17%) described free fluid in the cervical canal, a location not included in UltraSTAR's concept set. Twenty eight (14%) comments made comparisons with findings from a previous study. Nine comments (5%) were inappropriate in that they could have been expressed using the UltreSTAR concept set alone. The remaining 86 comments (43%) were classified as miscellaneous, most being used less than five times. Almost none of these, however, were so idiosyncratic that they would require natural language.

Figure 3

Variation in data entry times for individual sonographers. Box plots are shown for individual sonographers, arranged by the total number of reports generated by each person.

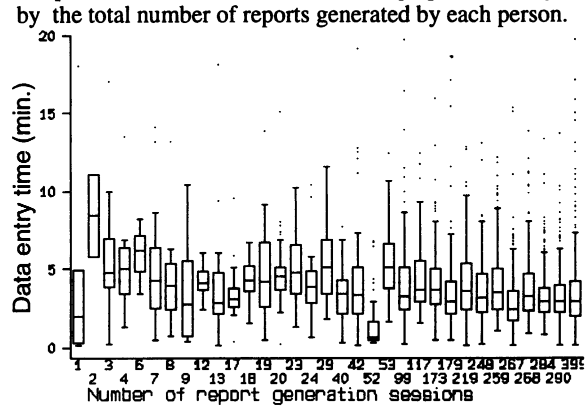


Table 3

Completion rates of UltraSTAR reports vs. narrative reports for six essential data elements in follicular monitoring ultrasound exams.

(*: significant difference, P<.001, Pearson's χ^2-test)

	Completion Rate	
Data element	UltraSTAR	Narrative
Uterus (any description, including "normal")	100.0%*	95.8%*
Endometrial thickness	99.5%*	95.8%*
Right adnexa (any description)	99.9%	100.0%
Rt. ovary simple cysts (or "no simple cysts")	94.0%	93.0%
Left adnexa (any description)	99.9%*	98.6%*
Lt. ovary simple cysts (or "no simple cysts")	92.8%	91.5%

Referring-Physician Satisfaction with Outline Reports

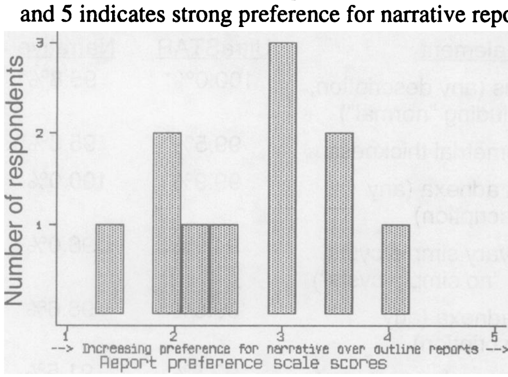
Scale testing. Of the 12 gynecologists who have been the primary recipients of UltraSTAR reports, 11 returned our survey after one round of re-surveying nonresponders. Of the 16 questions administered, the four Likert-scale questions shown in Table 4 produced the most reliable responses. A summary preference scale constructed from these four items shows good internal consistency in our sample of 11 responses (Cronbach's alpha = 0.81). Factor analysis shows that one primary factor accounts for most of the variation in the responses to these four questions. This factor may be considered to be the reciepients' preference for outline reports over narrative reports.

Survey results. The mean score on our preference scale for the 11 gynecologists responding was 2.75 (95% CI 2.24–3.26), thus showing a trend toward preference for outline reports that did not achieve statistical significance. Figure 4 shows that the distribution of preference scores included some individuals with a strong preference for outline reports, some who were neutral, and some who moderately preferred narrative reports.

Table 4
Items forming the report preference scale.

I prefer narrative reports to outline reports.
Outline reports make my work easier.
I would like to see more exam types reported in outline format.
Given a choice of ultrasound facilities, I would refer patients to one that returns outline reports.

Figure 4
Histogram of preference scores from survey of referring physicians. A score of 1 indicates strong preference for UltraSTAR ourline-format reports; 3 indicates neutrality, and 5 indicates strong preference for narrative reports.



DISCUSSION

This study shows that structured data entry can be implemented and evaluated in a real patient care environment. Our evaluation further shows that structured data entry can provide high quality reports and user satisfacion even though problems of concept representation and data entry time remain to be solved.

Report quality is measured in this study by referring physician satisfaction with reports and by report completeness. UltraSTAR is unique among structured data entry systems in its generation of structured, outline-format reports. Referring physician satisfaction with these reports was measured by a survey scale on which a score of 1 indicates strong preference for outline reports, 3 indicates neutrality, and 5 indicates strong preference for outline reports. Referring physicians did not show unanimous preference for our outline reports over narrative reports. We can conclude, however, that on average narrative reports are not preferred over outline reports, since the 95% confidence interval of the mean preference score result excludes any preference stronger than 3.26. Further work is warranted toward improving the clarity of outline reports as judged by those reading them. Optimal report format might also be studied objectively by measuring reading speed and comprehension for alternate formats.

Report completeness was somewhat higher for UltraSTAR reports than for dictated reports in three of six data elements considered essential for pelvic ultrasound reports. Although these differences were statistically significant they may not be clinically significant, as completion rates were high in both samples. This comparison looked only at the simplest (and most common) type of pelvic ultrasound exam. Examining completion rates for more complicated exams may reveal larger differences. UltraSTAR does not force the user to complete any data element, so any enhancement of completeness it causes is probably due to a reminder effect of having relevant concepts presented. This reminder effect was not strong enough, however, for UltraSTAR to reproduce the 100% completeness rate found by Kuhn in structured endoscopy reporting [2].

An important measure of UltraSTAR's success is the high level of satisfaction found in our survey of attending radiologists. Our sample of four responding radiologists is quite small, however. It will be important to continue to monitor attending satisfaction as the use of structured data entry broadens.

Although our surveys of users and referring physicians showed enough reliability to support conclusions in this study, neither survey can be considered thoroughly tested, each having been used on less than 15 individuals. There is need for further development of methods for evaluating satisfaction with and effectiveness of medical information systems.

Two features of UltraSTAR—collaborative reporting and integration with an existing information system via HL7—are unique among structured data entry systems and may account for much of UltraSTAR's success. Collaborative reporting allows each participant in patient care to contribute to a single report documenting a single patient study. This collaboration stands in contrast to the usual clinical documentation, in which each health care worker documents observations and interpretations separately, and often redundantly. UltraSTAR's HL7 link to the radiology departmental information system allows UltraSTAR reports to substitute for dictation.

UltraSTAR's mean overall reporting time of 5.25 minutes per report and its modest scores on the QUIS indicate room for optimization in the user interface. Speed issues that could be addressed include heavy Ethernet traffic, slow printing, suboptimal layout of data-entry forms, and the interpreted execution of our code in SuperCard. Meanwhile, the neutral overall satisfaction lavels among sonographers indicate that UltraSTAR's user interface is at least tolerable.

UltraSTAR's concept set was complete enough to report 75% of the exams in this domain without further text annotations. Preliminary examination of text annotations shows that the majority would be amenable to coverage in an expanded concept set. We also find that text comments were very seldom used inappropriately when content should have been expressed using the controlled concept set. These results indicate the success of UltraSTAR's hybridization of structured data entry with free text annotations. Further investigation will follow the proportion of reports using free text as the concept set is improved. This improvement is occurring in both the content and the structure of the concept set. Expansion of content is being prioritized by standardizing expression of the most frequent free text annotations. Work on the structure of our concept set focuses on moving our content to a semantic network model [19] and on general methods for building and using such models in structured data entry [20].

The UltraSTAR concept set has additionally demonstrated that structured reporting requires more detail than is typically present in existing controlled vocabularies[21]. The UMLS Metathesaurus [22] contained exact matches for 14% of UltraSTAR's concept set, while SNOMED [23] contained 23% and ACR codes [24] contained 19%. UltraSTAR's concept set is therefore being contributed to the UMLS Metathesaurus.

UltraSTAR's success has resulted in a growing body of routine patient data that *consists of* standardized codes, rather than being coded after the fact by a third party. Perhaps the most important avenue of future investigation will be in structuring systems to acquire routine patient data in a way that will maximally contribute to medical knowledge and the practice of evidence-based medicne [25]. To avoid biased outcomes data, such systems may need to incorporate randomization into routine patient care in areas of diagnostic and theraputic uncertainty.

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